How and When to Use Six Sigma Problem Solving in Your Lean Journey

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The core principle of Six Sigma is Problem Solving of chronic problems, yet this is the weakest area of the initiative. Analyze phase is often described as 'then a miracle occurs'

This presentation is intended to provide an introduction to a disciplined structured approach to determining root cause. This method is based on sound scientific and statistical principles.

Although we will only be able to cover enough material to provide an overview, there is substantial extra materials and references/bibliography for further study.

What are some of the problem solving methods – not statistical tools – that you have used?

What is a problem[1]?

An undesired situation whose root cause is unknown

- Cycle time is too long
- Inventory is too high
- Product is on backorder
- Customer complaints are too high
- Yields are too low
- Rework is too high

These statements are often in the class of ‘business problems’

Further drill down will often result in a set of unique specific problems to be solved

The Eight Wastes

1. Overproduction
2. Excess inventory
3. Transportation
4. Non-value added processing
5. Waiting
6. Excess motion
7. Defects
8. Underutilized people

Different problems require different methods

The eight wastes define the problem solving space

The eight wastes are all inter-related – one waste will result in most of the other wastes.

Lean methods identify the largest wastes, lead us to the causal waste and often provide us with the solution to that waste.

Defects is the one waste that can be the most resistant to lean problem solving methods

Lean problem solving while relatively straightforward compared to 'technical' Six Sigma quality problem solving is NOT easy.

If inventory is evil, defects are the root of all evil!

Lean methods

Diagnostic tools:

- mapping (value stream, spaghetti, *etc*.)
- standing in the circle
- five whys
- single piece flow

Solutions:

- line balancing
- Kanbans
- 5S
- Visual workplace

Lean problem solving while relatively straightforward compared to ‘technical’ Six Sigma quality problem solving is NOT easy.

What are “Six Sigma” problems?

Problems whose causal mechanisms are based in physics and/or geometry.

Problems whose causal mechanisms are based in human error or mistakes.

The best method for human error or mistakes is the Apollo method covered by Dean Gano

Common root cause approaches

Theory based

- Brainstorming & fishbone diagrams
- Scientific theories of how a specific factor or event creates the problem (fault tree)

FMEA

Trial and error – often solution based

Experience based

5 Why

“Is, Is Not” (Kepner-Tregoe)

Theories include pet theories, favorite theories, agenda driven theories

Brainstorming often involves multi-voting and other consensus based ranking schemes to select theories to test. “science is not a democracy” “public opinion polls have never changed a law of physics”

Experience based: “the last time this happened”

Two basic approaches[2,3,4]

Cause to Effect	Effect to Cause
• Conjecture : Brainstorming → fishbone diagrams → multi-voting	• Evidenced based
• **Proves** a cause creates an effect	• **Disproves** potential causes
• Swing for the fence	• Considers all potential causes
• Divergent – random searches	• Iterative approach
• One factor testing or fractional factorials	• Convergent
• **Focus is on how the system works**	• Quick tight experiments
	• **Focus is on how the system fails**

Cause to Effect: The literature has a lot of references to the various techniques, but little rigorous explanation of how to use the techniques.

Effect to Cause: The literature has few references to the various techniques but tend to be much more detailed and rigorous in their use. However, the references are very disparate and there is very little in the literature that synthesizes the techniques in a coherent and systematically useful manner.

"A bad system will defeat a good person every time"
– W. Edwards Deming

Cause to effect can work, it's just not very efficient (low batting average).

It's very seductive since it often promises a quick discovery of the cause or a solution. What most people forget is that there are too often many iterations of the 'quick' approach and too often the solution doesn't work.

I often hear complaints that the process is too 'disciplined' – but don't we expect operators to follow procedures? I also hear that the process is too mechanistic – it's not sciency enough. Or doesn't promote creativity.

5 essential elements to the 5 whys

1. The question “why did this problem occur” is a single layer at a time question, truly like peeling an onion
2. The strategy of the questioning must be aligned with the nature of cause and effect systems
3. Questions must be carefully structured to yield conclusive answers
4. Each layer must involve a carefully constructed split of the system such that the approach converges on the causal mechanism
5. Sound experimental approaches are required to properly answer the question.
6. *Asking “why” 5 times is a rule of thumb, not a precise requirement*

A convergent process of elimination

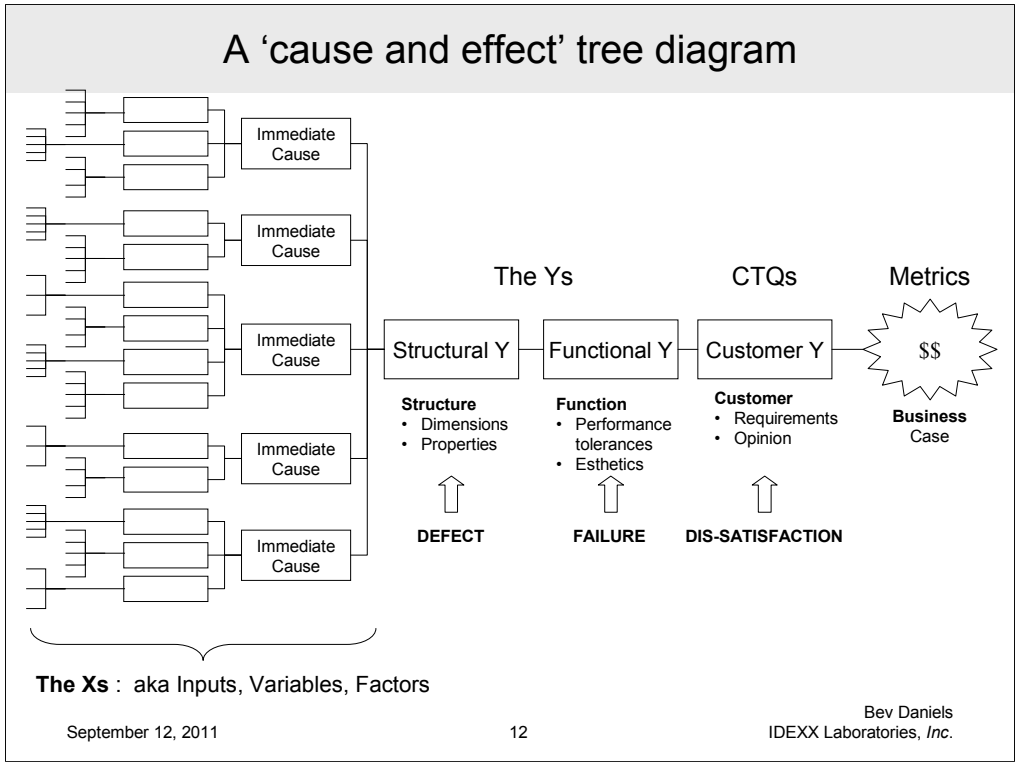
Begins with highest level of immediate mutually exclusive and exhaustive **causal categories** and focuses on eliminating or disproving each category as containing the root cause.

Primary focus is on how the system has failed to work.

Categories contain related causes and causal systems.

Early in the diagnostic process the potential causes are grouped by their effect on The Y. It is not necessary to know or list the individual factors at this point.

A cause can only exist in one category.



Although the individual factors are highly confounded, it is easy to unconfound the single category that contains the causal mechanism.

Now let's look at the tree in some detail…

Definitions

A **defect** is a static condition. . A nonconformance to a specification of a structural dimension or property (such as found on a blueprint)

A **failure** is a dynamic condition: a failure of a performance characteristic. The product or service doesn't function as intended.

Failure modes

A failure mode is a way in which a failure can occur; it is not a cause.

Individual performance characteristics may have multiple failure modes.

These failure modes may be the result of different causes, or may simply a single cause that results in different modes depending on the state of the causal factor:

- Complete non function
- Partial function
- Intermittent function
- Unintended function

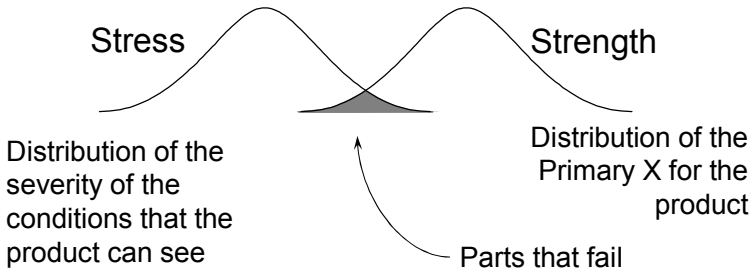
True defects

A ‘true’ defect eventually results in a failure.

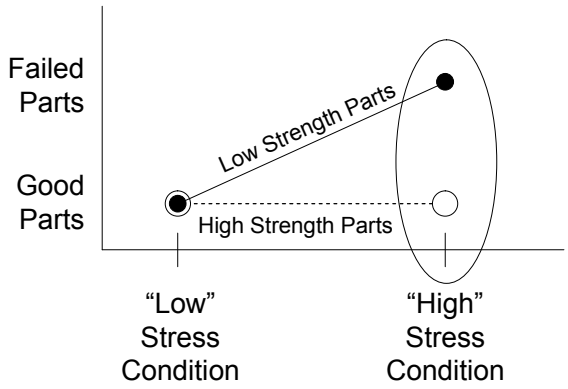
Some defects may require time or other stresses to result in a failure. (It requires a **condition for failure**)

Interaction of conditions & product

When product that has variation in some critical characteristic is subjected to conditions that also vary, failure will only occur when the conditions are “bad” and the product is also at a “bad” level:



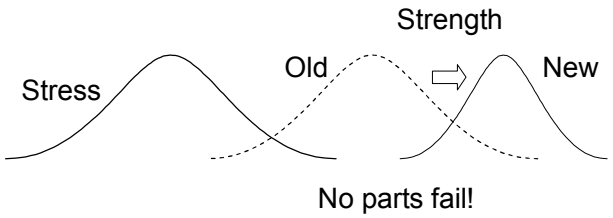
The interaction diagram



Analysis & Experiments must be under the "bad" or "high" stress condition to be meaningful

Increasing “strength”

If the “stress”, or conditions for failure, cannot be controlled, it is necessary to increase the “strength” of the product...



No parts fail!

Test under worst case conditions

Once the conditions for failure are known and defined all subsequent testing must take place under the same conditions that can cause failure

Root cause

An actionable factor, that if corrected or controlled, will prevent future occurrences.

Root causes are physical causes and are uniquely related to the specific object which is experiencing the Problem

Root causes may be better described as causal *mechanisms*.

Other causes

Immediate cause: the factor that immediately causes the Problem. Fixing this will not prevent reoccurrence, but may enable containment rework/repair.

Intermediate causes: sequence of factors that lie between the root cause and the immediate cause.

Peripheral causes

Enabling cause: the defect exists and the enabling cause allows it to continue. Addressing this may enable better screening of the defect or Problem.

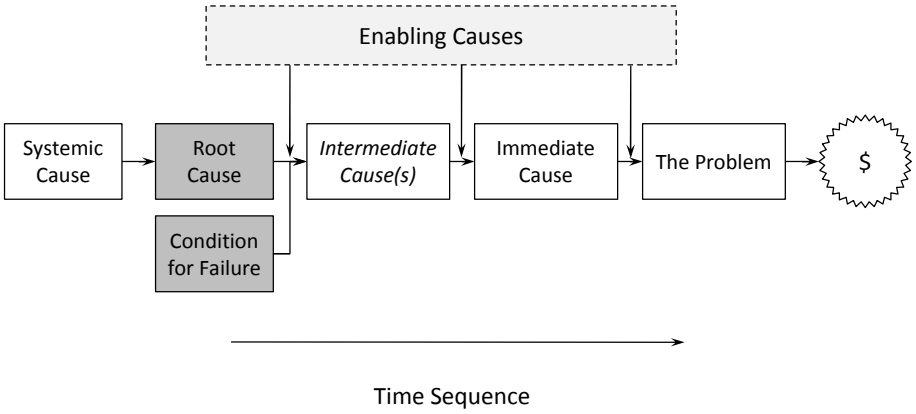
Systemic cause: an actionable factor that if corrected or controlled will prevent future occurrences on similar objects. (Systemic causes are typically business process or system related)

Until the causal mechanism is determined and understood, discussion of these causes are diversionary; addressing them will not solve the current Problem

Enabling causes can and should be addressed during the diagnostic process IF they can improve the measurability of the Problem or enable better screening to provde effective containment of the Problem.

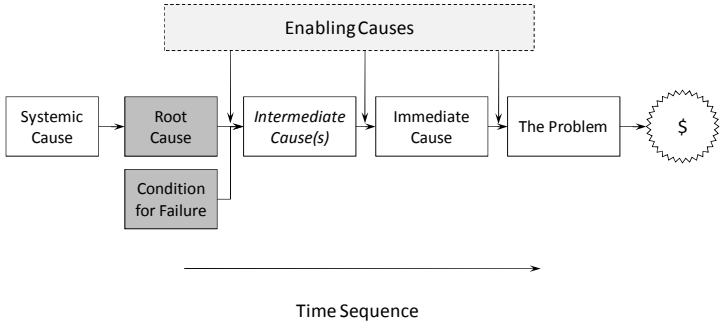
Systemic causes cannot typically be effectively addressed until the causal mechanism is known. Discussion of a systemic for an unknown physical cause is conjecture.

Sequence of causes



Understanding the causal mechanism

It is the understanding of the **causal mechanism** that enables us to devise a viable solution to eliminate or significantly reduce the Problem.



The Titanic: a simple example

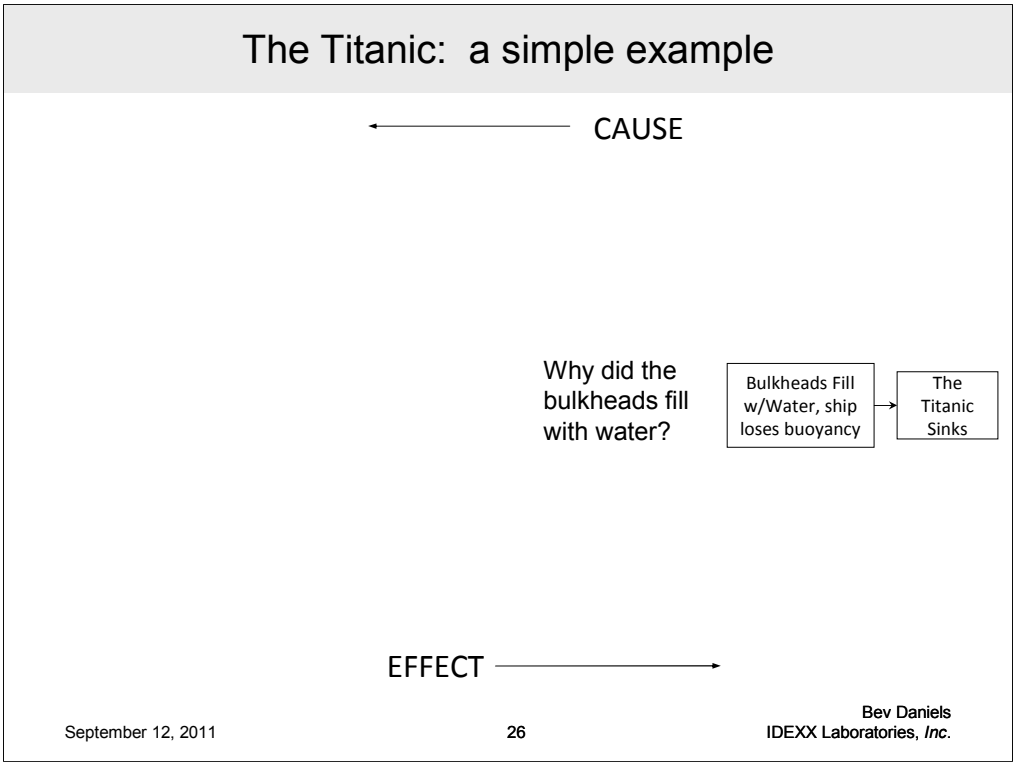
CAUSE ←

Why did the Titanic sink?

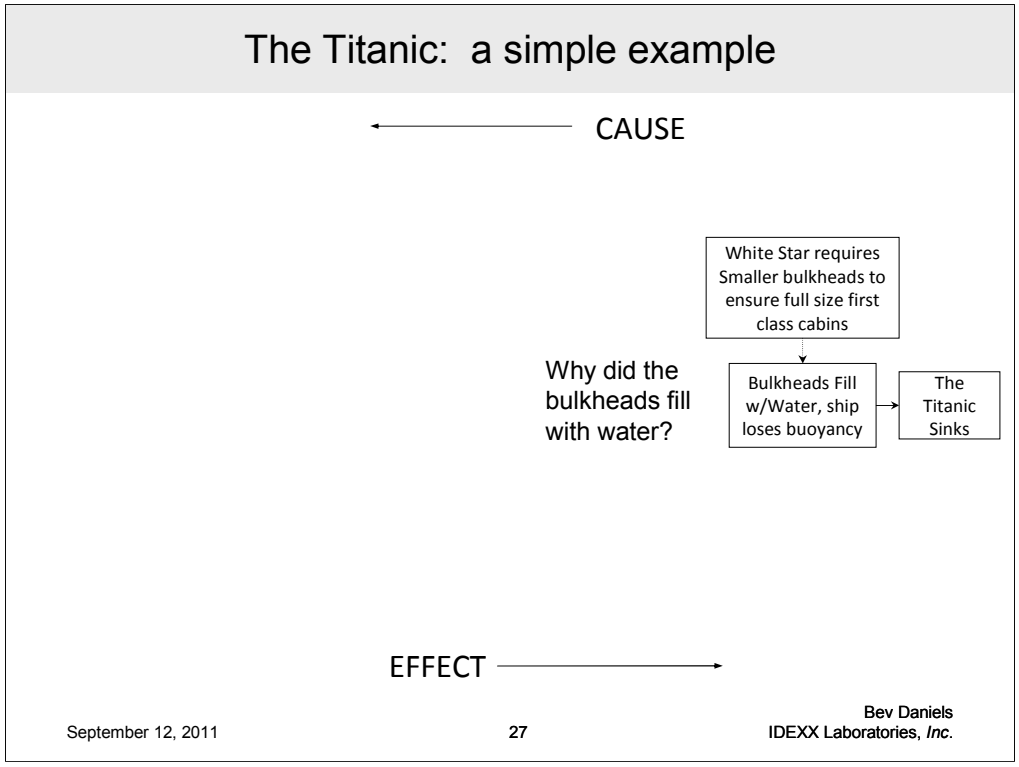
The Titanic Sinks

EFFECT →

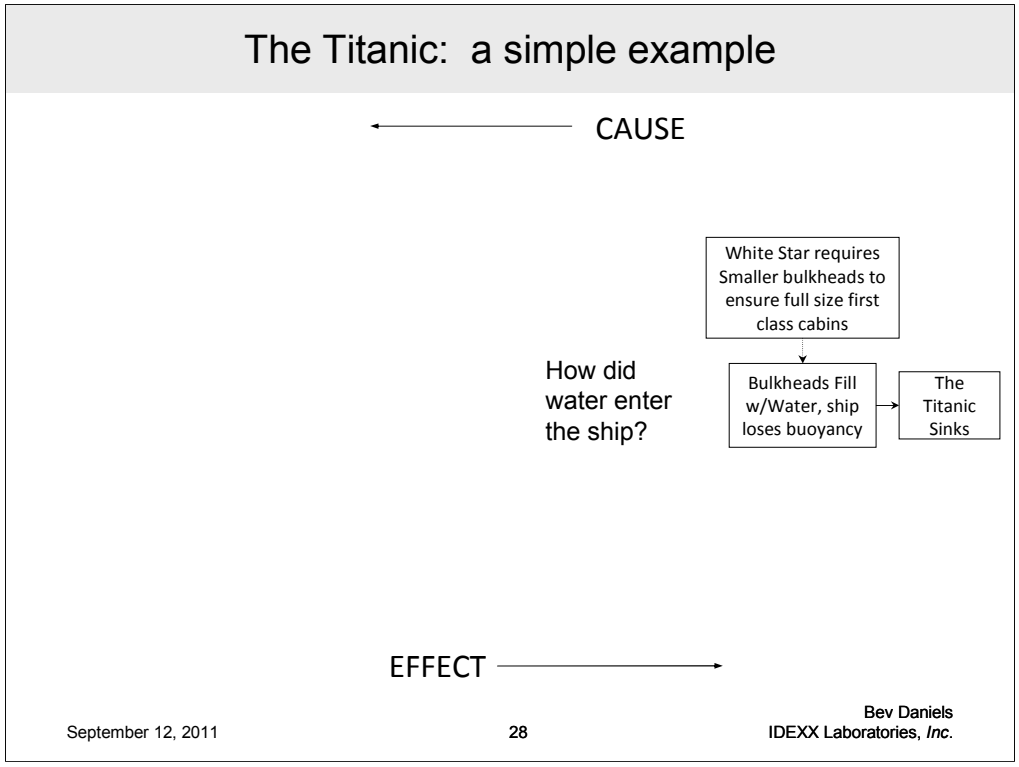
The Titanic: a simple example



Don't skip the 'obvious'; if it's a incontrovertible fact, document it; if it's an assumption, test to disprove.

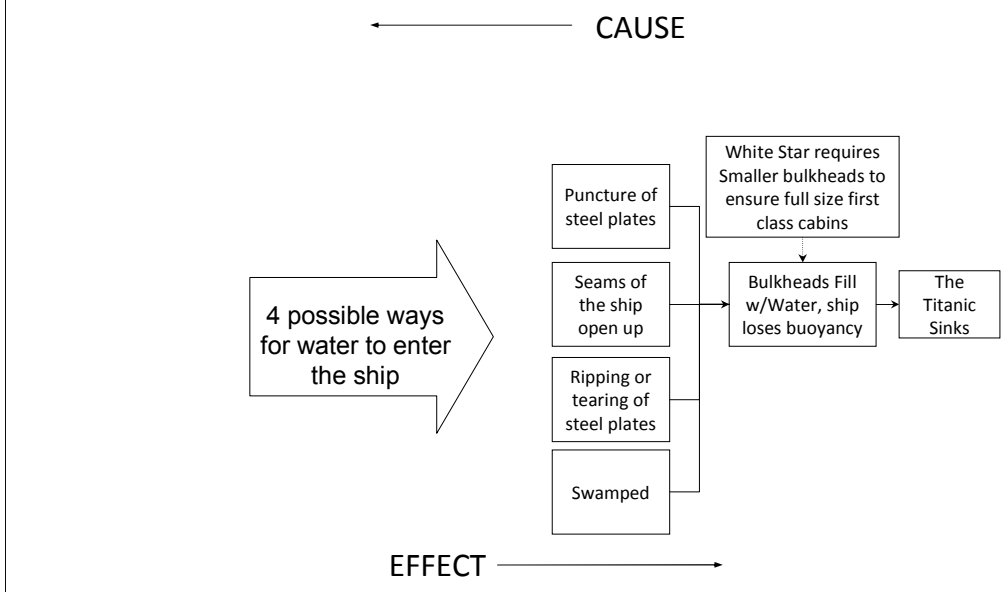


An enabling cause – the smaller bulkheads filled with water faster than larger bulkheads



A better question than 'why did the bulkheads fill with water". This is a "what's happening" question.

The Titanic: a simple example



In order to answer this question, we need specific scientific proof.

The causal system of the sinking of the Titanic

CAUSE

White Star requires Smaller bulkheads to ensure full size first class cabins

Why did the seams open up?

Seams of the ship open up → Bulkheads Fill w/Water, ship loses buoyancy → The Titanic Sinks

Open Seams on Olympia

EFFECT

Bev Daniels
IDEXX Laboratories, *Inc.*

Again this question requires specific scientific proof…

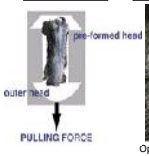
The causal system of the sinking of the Titanic

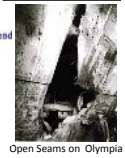
CAUSE

White Star requires Smaller bulkheads to ensure full size first class cabins

Why did the rivets shear?

Rivet Heads Shear → Seams of the ship open up → Bulkheads Fill w/Water, ship loses buoyancy → The Titanic Sinks





Open Seams on Olympia

EFFECT

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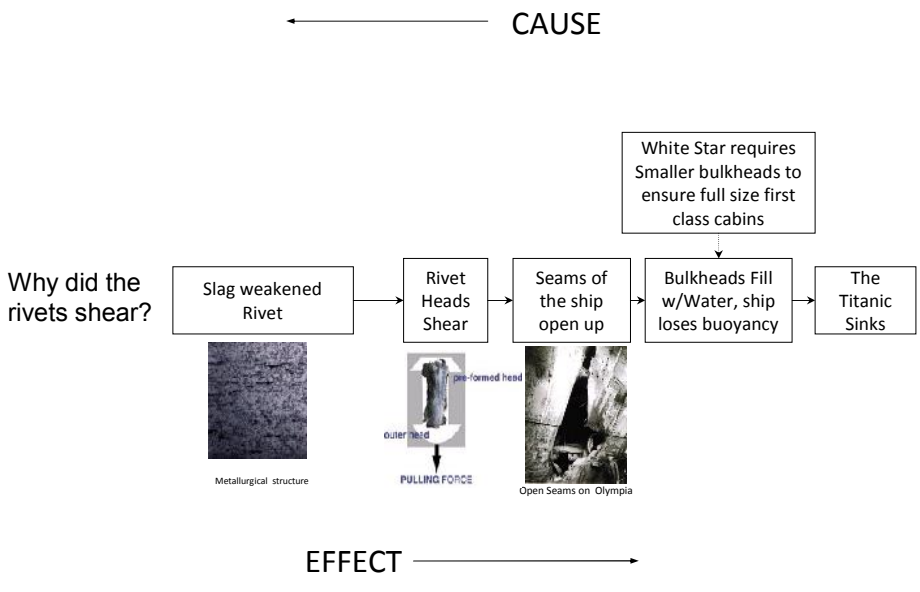
Rivets found in the debris field were found in great numbers to have been sheared at the rivet head. Shear forces are very easy to identify under metallurgical examination.

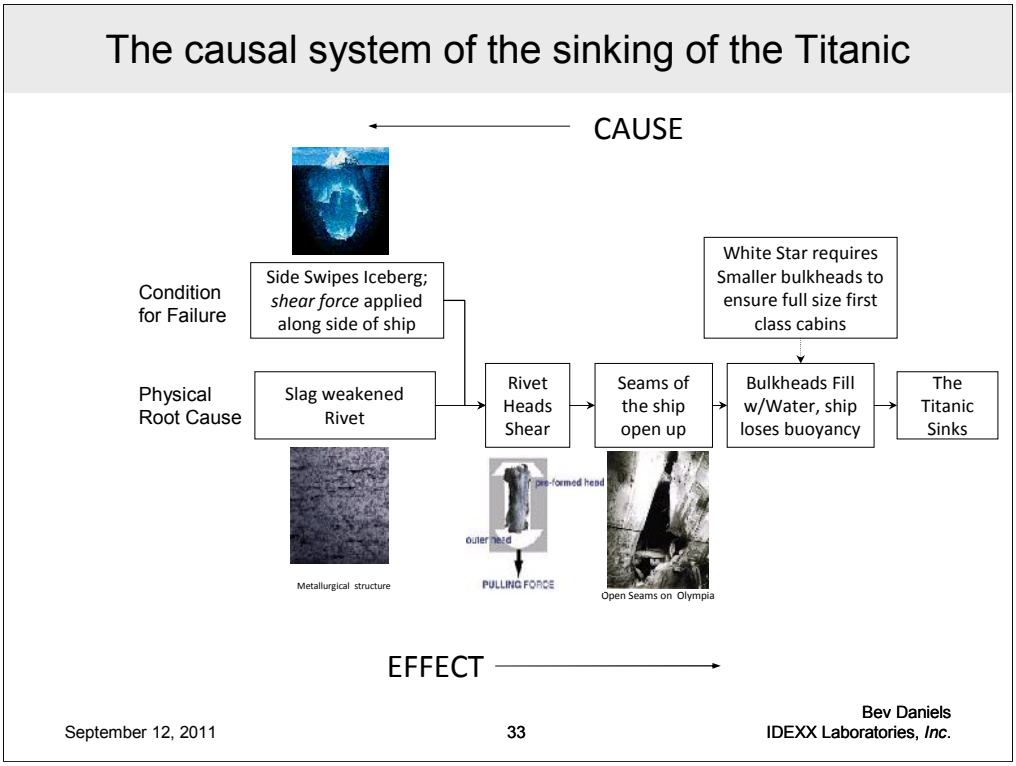
Eye witness – ear witness – accounts reported hearing 'popping' noises like ball bearings or marbles hitting the floor at eth time of the impact.

The causal system of the sinking of the Titanic



Metallurgical examination revealed the presence of extensive slag in the rivets which is known to weaken the strength of metal.

But the rivets didn't shear spontaneously, they had help…

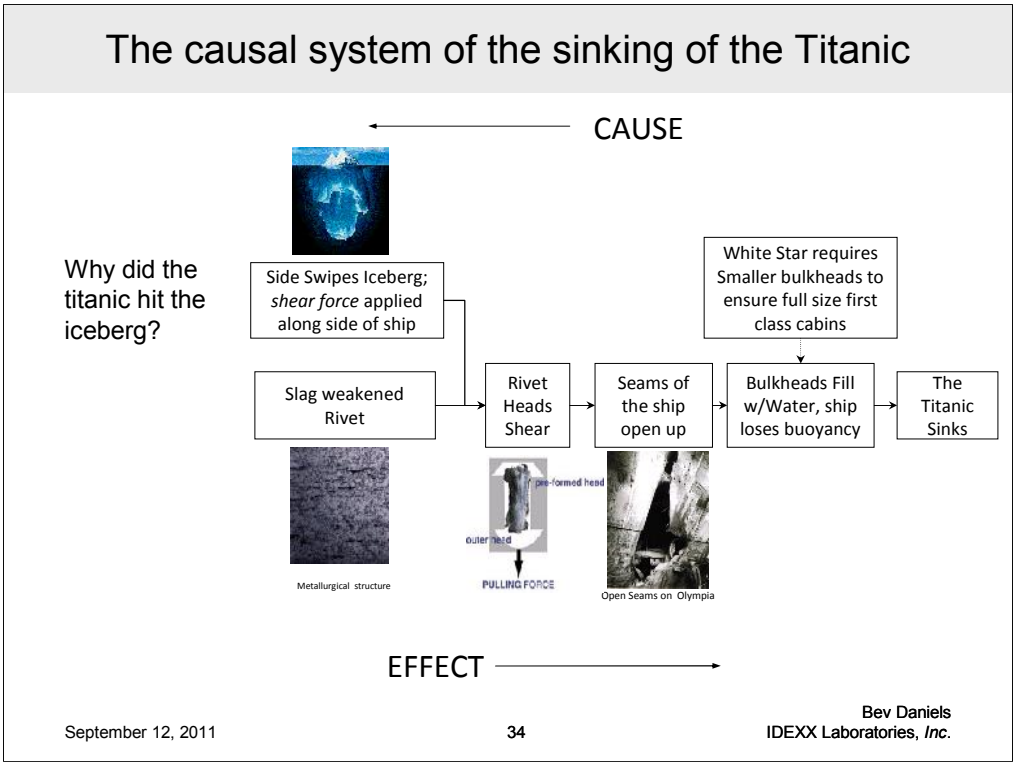


4 Whys (2 asked twice) to get to causal mechanism.

This is the classic strength-stress interaction.

We could go further and indentify why slag was in the rivets – although this was a scientific/manufacturing constraint at the time. But at this point we have enough specific information about the causal mechanism to develop a viable solution. The seams need to be held together by a stronger fastening system.

In this case actions to guard against the condition for failure are futile. **Any** sideswipe can cause the rivets to shear; in fact this is how the Olympia failed..



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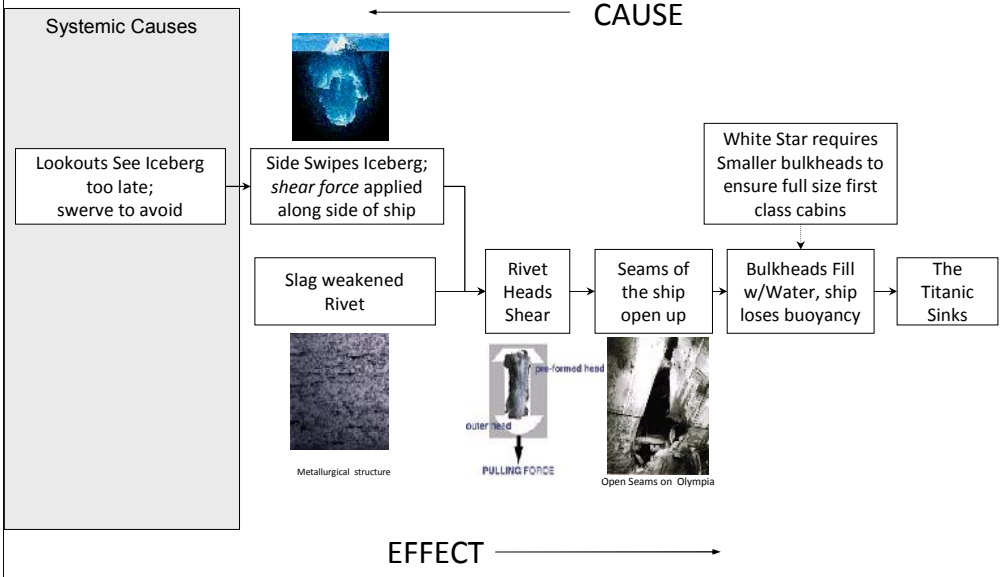

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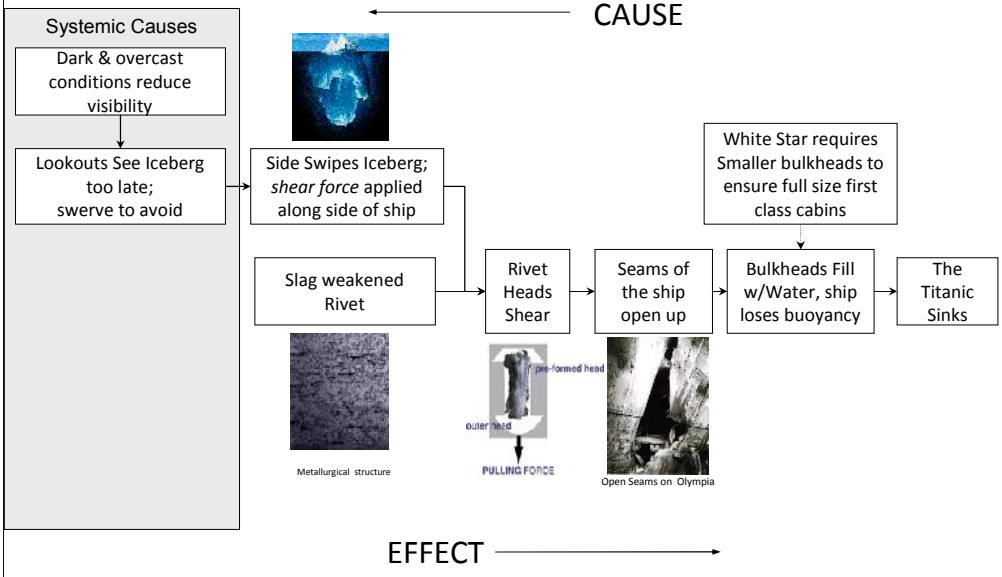

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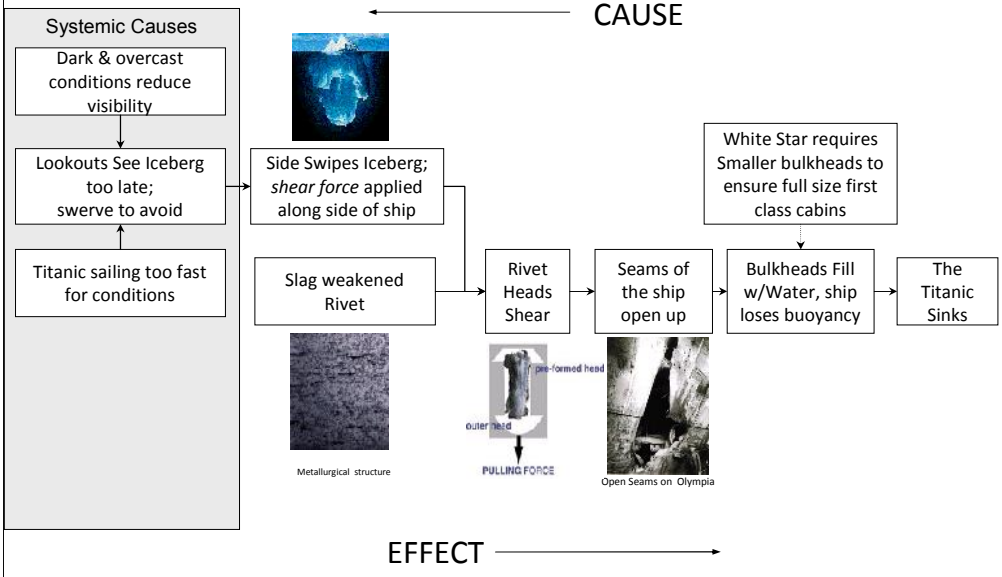

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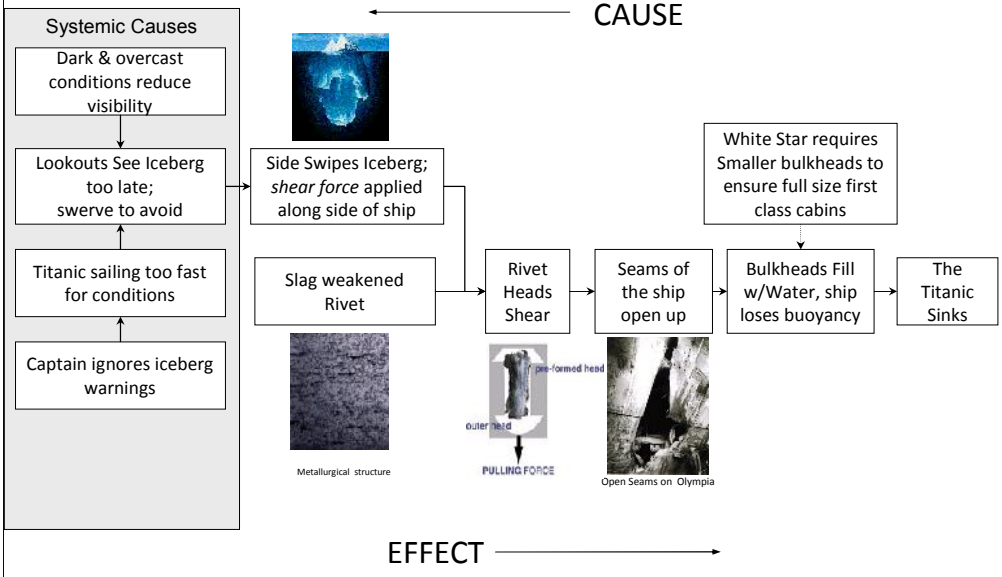
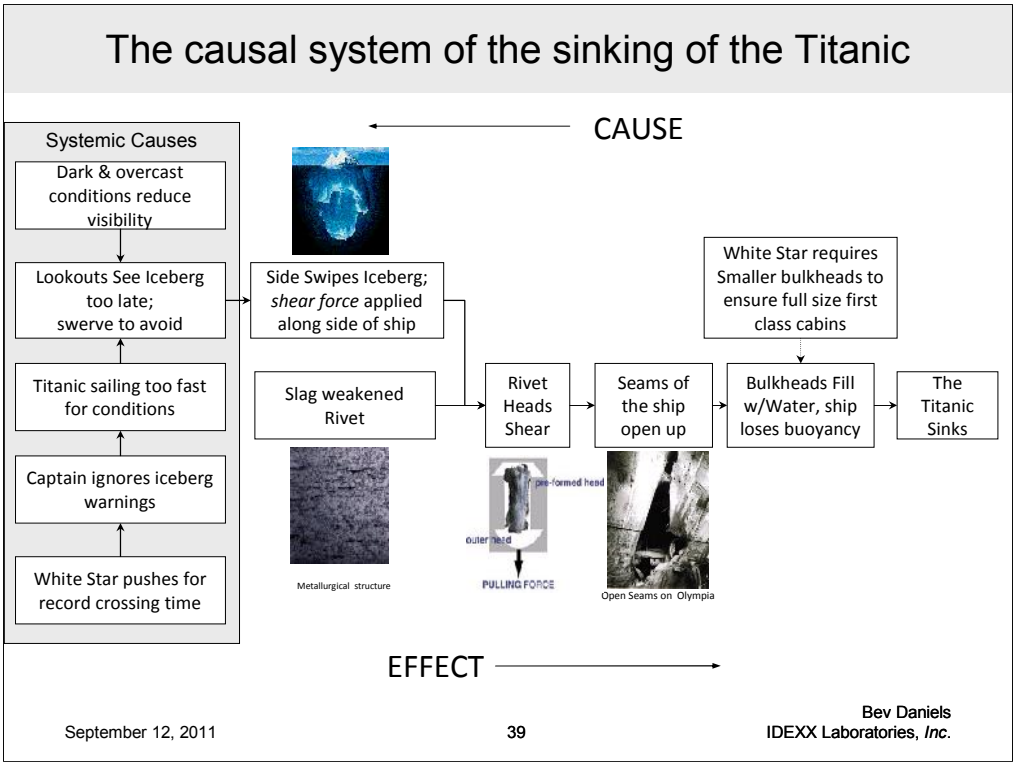
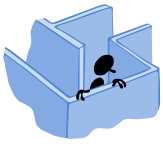
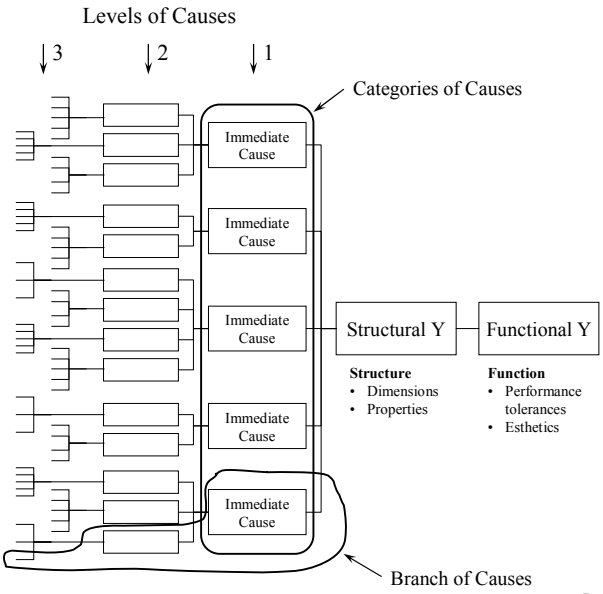




This is a relatively simple example that really didn't require sophisticated experimental structures to answer any of the 5 Why questions. It does show the basic flow of causal mechanism and the separation of systemic, enabling and physical causes.

The Effect to Cause diagnostic tree





Using the Effect to Cause tree diagram

All potential causes are not listed on the diagram.

- Only one level at a time is listed.
- Each level contains a **mutually exclusive and exhaustive categorization of the causes**
- Only those categories of causes that are investigated are listed.
- Investigation of each category is to determine if it contains the primary cause or not.
- The next level is not listed until the previous level is fully investigated and only the category containing the primary cause remains
- Only those branches that are found to contain the primary cause are investigated

This is accomplished by analyzing it's affect on Y: how much does The Y vary as this category varies. It is not an analysis of how much the category itself varies.

Disprove

Progressive searches utilize experimental designs that **simultaneously test all alternative theories** and seek to **disprove whole categories of causes**, rather than to prove a single factor or causal category is the root cause.

The half-split technique and the binary search[5]

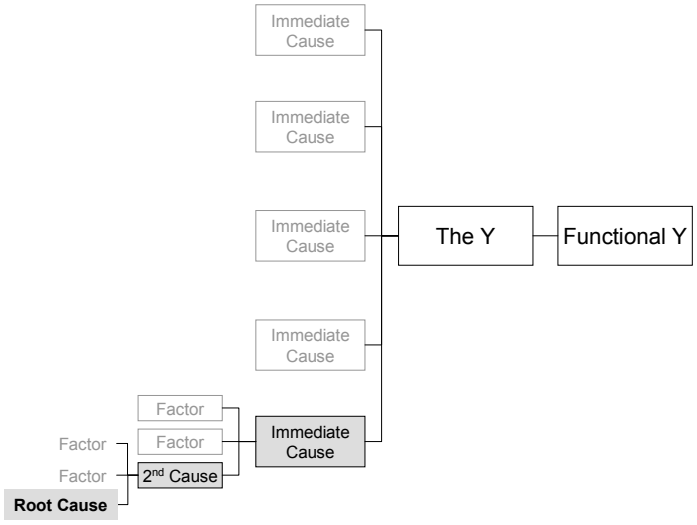
The majority of the experimental tactics used in a progressive search are focused on elimination of causal categories.

The half split technique is a time honored approach to progressively cut a system in half until the root cause is all that is left.

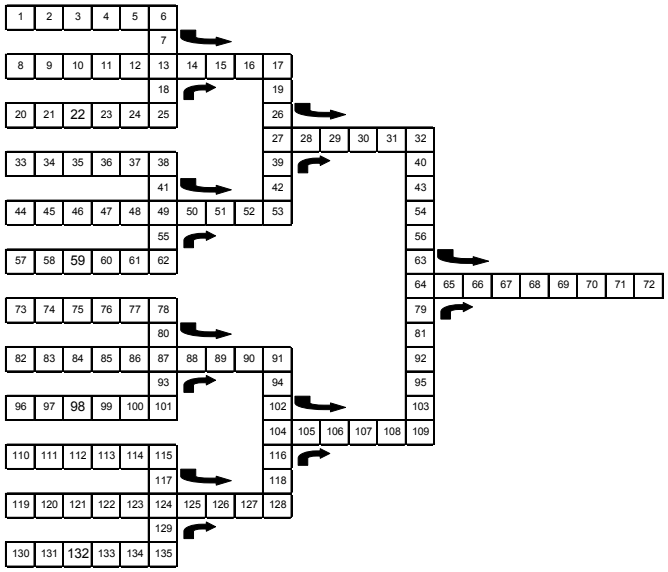
Not all situations lend themselves to the half split technique but will be suited for a variant of it; our experimental design may split the causal systems into thirds or quadrants, *etc*.

A classic example is The Dictionary Game: One player picks a word from the dictionary and the other player tries to guess the word. The guessing player then attempts to determine what the selected word is by asking questions that can only be answered with a 'yes' or a 'no'. The weakest approach is to ask very specific questions: "is it this word or that word". They may elect to ask such questions as "does it start with an 'A'" or "is it an animal, vegetable or mineral", or perhaps even "is it a noun, verb, descriptor or interjection"? While each of these questioning strategies has some 'elimination' power, they are weaker than simply asking "is the word in the first half of the dictionary" and progressively cutting the part of the dictionary that contains the word in half until the guessing player is down to the last remaining word. The player doesn't need to know what the word is, how to pronounce it or even how to spell it; they simply need to have the dictionary in their hands.

A true Effect to Cause tree diagram



A simple split exercise[5]

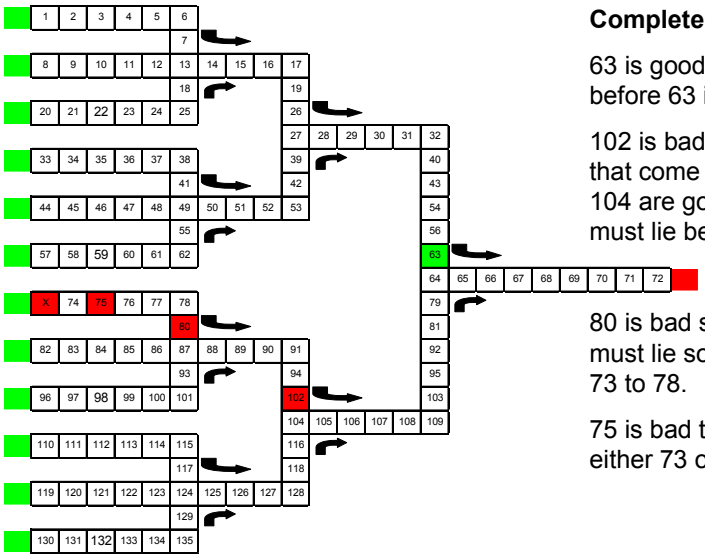


This example is a simple linear flow with no interactions and only one causal factor.

It also utilizes a deterministic approach (a binary response) since this is a single system with no intermittent failures or mix of units some of which fail and some of do not fail. This approach is used to demonstrate the technique..

If this were a real world example, there would be multiple units having this system and the failure rate will most likely not be 100%.

The Answer



Completed in 5 moves

63 is good so everything before 63 is also good.

102 is bad so the elements that come to the junction at 104 are good; the case must lie before 102

80 is bad so the cause must lie somewhere from 73 to 78.

75 is bad the choice is either 73 or 74.

The choices of 75 and 73 result in the minimum moves of 5. If the choice had not been as 'lucky' there might have been 6 moves…

If there were a secondary cause (less effect than a primary cause) the investigator would quickly detect this as the failure rate would not go to zero when the primary cause was determined and/or controlled.

If there were two primary causes, the investigation would also determine this as different causal mechanisms are discovered and the total failure rate would not go to zero upon correction or control of one of the causes.

It is also important to remember that the effect to cause 5 why approach requires the scientific and practical understanding of the system itself. It doesn't rely solely on statistical 'black box' thinking.

This causal system is amenable to the half split technique.

Other systems may require multi-way splits.

Split categories

Split categories must be exhaustive and mutually exclusive

All possible splits are either

- Functional
- Structural
- Temporal

Some causal systems will use hybrids of the 3 primary split categories

Functional causal categories

Functional Failure Modes

Identify which of the potential failure modes is most prevalent

Broad "use case" functional categories

- User
- Product
- Consumables, supplies
- Environment
- Use conditions

Specific functions or energy transfer paths

Structural causal categories

Location

- Within piece
- cavity to cavity
- station to station
- line to line
- plant to plant
- region to region

Components

- Sub-assemblies
- Components
- Raw materials
- Process (assembly or process methods)

Specific features, dimensions and/or properties

Temporal causal categories

Temporal

- (Within Piece), Piece to piece, lot to lot, vendor lot to lot, month to month, season to season *etc*.
- Product use: during use, use to use
- Operator to Operator
- Within a process; step to step or operation to operation.

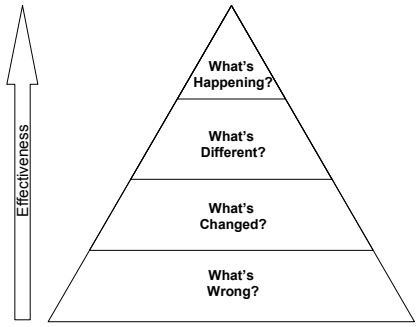
The need for speed

There may be multiple viable choices for causal categories, particularly for the first level.

The best choice is often determined by **what can be easily or quickly tested.**

Four questions: framing the Effect to Cause search[6]

1. **What's Wrong**
2. **What's Changed**
3. **What's Different**
4. **What's Happening**



What's Wrong: The most common approach and works well with simple Problems and obvious (easily observed) causes.

What's Changed: The weakest question. It requires that the cause was known, measured and recorded. It is also prone to *post hoc, ergo propter hoc** errors.

What's Different: Involves determining the differences between the diagnostic pairs. When used with a convergent elimination strategy it is highly effective.

What's Happening: This is the strongest question. It includes the other three questions as appropriate and when coupled with a convergent elimination strategy is the most effective approach for highly complex problems

These questions help to determine which split will be the most effective: Functional (typically answers the question "what's happening"), Structural (typically answers the question: "what's different") or temporal (Can answer the question what's happening at a high level)

When a problem is a result of a change in a causal factor, it is usually important to eventually answer the question "what changed"; however, it is often impossible to answer this question as a strategic 5-why question…

Diagnostic pairs[1]

The Effect to Cause approach is a progressive search using diagnostic pairs.

A diagnostic pair is a causal category that contains two distinctly different results in The Y.

Comparisons of the diagnostic pair will yield an actionable causal factor.

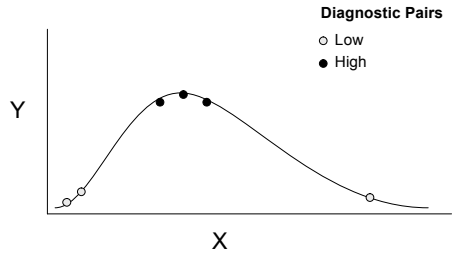
The most effective diagnostic pair is one that is as close in time and space as possible.

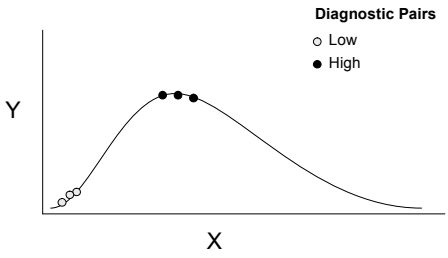
Examples of diagnostic pairs[1]

- Good and bad parts
- Good and bad events within the same part
- Raw materials or components associated with good and bad parts
- Manufacturing lines, processes or Customers associated with good and bad events.

The curvature boogeyman: Many engineers tend to worry about curvature when dealing with diagnostic pairs, reflexing to selecting a low, middle and high level in order to not miss any potential curvature. When using the 5 Why approach and working to the causal mechanism from the effect side, there is little chance that curvature – if it exists in the normal operating space – will be missed.

Diagnostic pairs are selected by their actual value in The Y, not by their value in the causal category. So if curvature exists it will be captured. The relationship between the causal mechanism and The Y will also be characterized in later stages (Improve) of the DMAIC process.





Start with a good problem statement[1]

Simple: object, defect format

Use only verified facts in the statement

In terms of the effect **not** the cause

"An approximate answer to the right question is worth a good deal more than the exact answer to an approximate problem." John Tukey

The observational study

The beginning of the Scientific Process is OBSERVATION. This requires observation of the actual process under Normal Operating Conditions.

If The Problem occurs in the field, then product that experiences the failure and product that doesn't experience the failure (but has had the same opportunity in time, usage, conditions, etc.) must be retrieved and run in-house.

If this is not possible, then product must be run under Customer conditions in-house to recreate the failures.

Observational studies are often a form of Temporal splits.

When the investigator also observes the failure itself (in the case of functional failures) they are answering the question "what's happening" and performing a Functional split.

Usefulness of the observational study

Understanding of the full range of variation in The Y

Understanding of any non-homogeneous variation which will drive sampling schemes for any invasive experiments.

- Largest components of variation such as run to run, time to time, vendor lot to lot, *etc*.
- Clustering of failures (a common occurrence with rare events, defect rate < 5%)

Understanding of Normal Operating Conditions including best and worst case.

Identification and separation of existing failure modes

The causal factor or many clues may actually be visible…

It's amazing!

The observational study also lends itself to a less rigorous, but quick assessment of the situation and the appropriateness of several alternative causal categories.

It can quickly point to the strategy that will be the most effective.

It's amazing the things you can see when you look!
Yogi Berra

Process & function maps

First level categories come from process maps, functional maps and knowledge of the functional components.

How is The Y created or used?

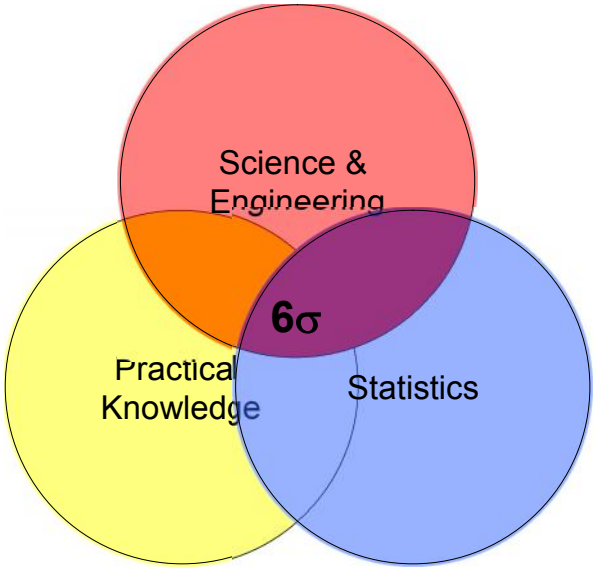
What **categories** of Xs will cause variation in The Y?

The first level should not be constructed until the process and/or function maps are created and understood.

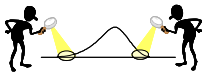
It is always helpful for the team lead – and team members where feasible – to carry around the part experiencing the Problem. Holding it, looking at it, playing with it, keep the leaders focus on the Problem part and it's function.

Process and function maps are often misunderstood and frequently drawn too large.

Six Sigma doesn't eliminate physics



Balance, Discipline and Structure



The biggest mistakes in formal or informal Problem Solving are a lack of balance, discipline and/or structure

BALANCE: testing all levels that are relevant

STRUCTURE: create statistical significance and practical importance

DISCIPLINE: execute the test protocol as designed

Balance

High and Low levels of the X (suspected cause)

Old and New: current method or part *vs.* the proposed solution to the method or part.

Sample sizes for each level must be equivalent; a ratio of no more than 3:4 is recommended if equal sample sizes can't be obtained.

Ensure that your data spans the full range of variation in The Y

Structure

Sample size and independent replicates

Simultaneous testing of all alternative theories

- Use of appropriate experimental controls: ensure that external extraneous changes are not missed or misinterpreted.
- Inclusion of changes in “experimentally uncontrolled” factors
- Randomization

Protocol:

- ensuring that the test conditions replicate normal operating conditions
- Ensuring that worst case conditions are correlated to normal conditions and are not beyond actual worst case conditions

Discipline

Don’t alter the test plan to chase an “observation” (*aka* shiny object) that may well be an isolated anomaly or coincidence.

Don’t alter the test plan to be quicker or easier midstream or without consultation

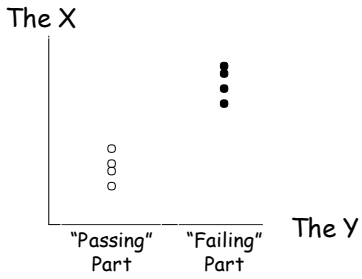
BE THERE – It’s amazing the things you can see if you look

Don’t throw out data you don’t like. If the data is a confirmed typo or experimental error you can remove from the statistics (Annotate its’ existence). If it’s extreme value without assignable error cause, leave it in.

Look both ways before crossing the street!

The initial analysis phase concentrates on determining the differences between the highest and lowest values of The Y.

When evaluating suspect Xs it is essential to ensure that the factor accounts for both high and low results in The Y.



Do not look only at the "bad parts".

The Root Cause factor is responsible for both the "good" and the "bad" results in The Y!

You have isolated the primary root cause when…

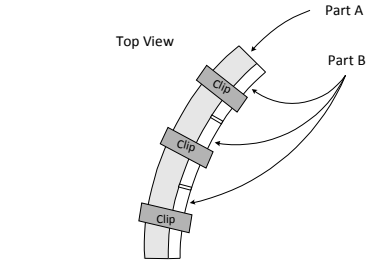
In order to ensure that you have isolated the primary root cause factor:

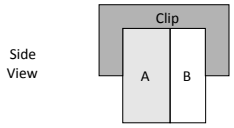
- **It is essential that your data spans the full range of variation in The Y**
- All other factors should not be held constant.
- All experiments (invasive) should be run randomly.
- Ensure that there are multiple independent samples (the number of data points does not equal the sample size!)

A turned dimension

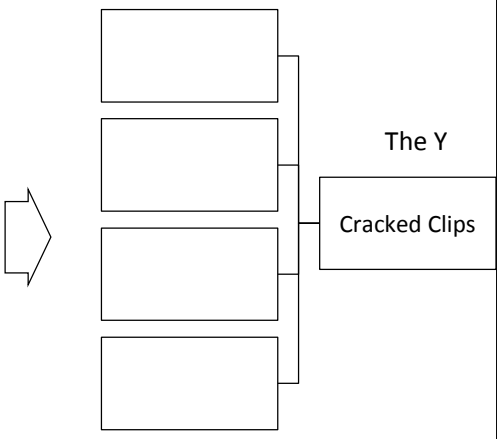
The Problem:

A 3 Component assembly is experiencing cracks in the clips and some loose B Parts...





What are the 'categories' for the first level?



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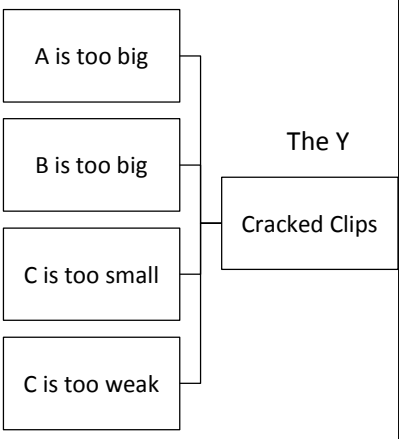
Effect to Cause 1st level split: structural



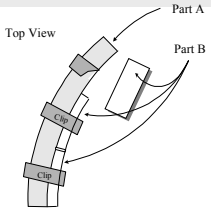
First experiment

Failed assemblies were returned form the field.

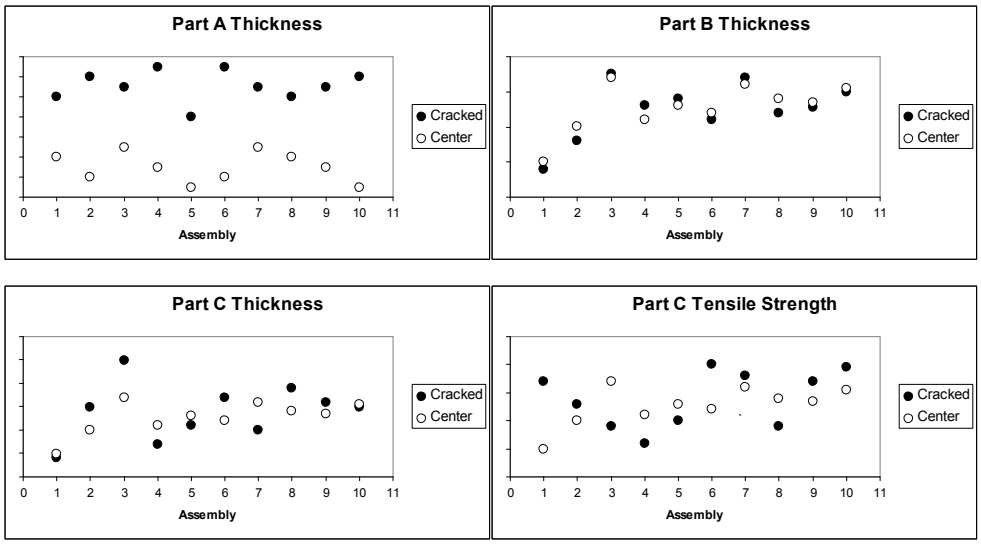
A “post hoc” analysis was performed

Since the center clips were never observed to be cracked, the center parts were compared to the end parts that exhibited cracks

This was a “paired” test with the center and end parts compared within each failed assembly: These two parts form the diagnostic pair.



The results

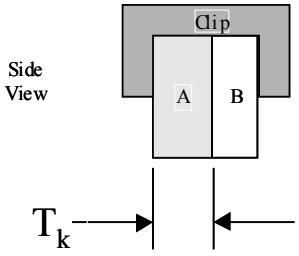


This comparison can also be displayed on a Youden plot. A systemic difference will display as a bias to a 45 degree 1:1 line

Part A is too thick

It was found that **Part A was larger in the cracking end clip area than in the non cracking center clip area**.

In fact it was found that the Dimension did not have to be out of spec to cause a cracked clip...



The turning process

Part A is turned on a fixture that holds 8 parts.

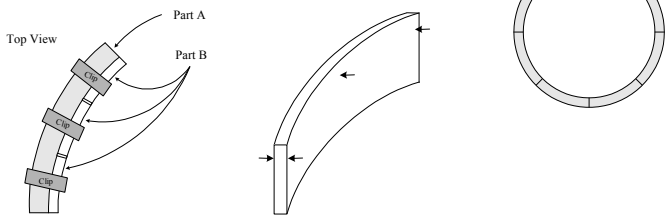
It takes 10 hours to turn a complete Set of 8 parts.

Three different lathes are used exclusively for producing these parts.

There is only one vendor for the castings.

What approach would you use?

What are the split categories?



Turning categories of variation

Within Piece

Piece - Piece = Within Fixture

Set to Set

Machine to Machine

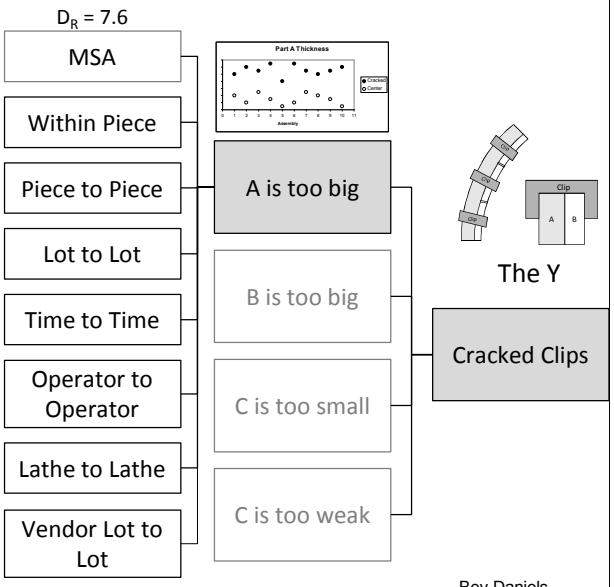
Operator to Operator

Time to Time

Shift to Shift

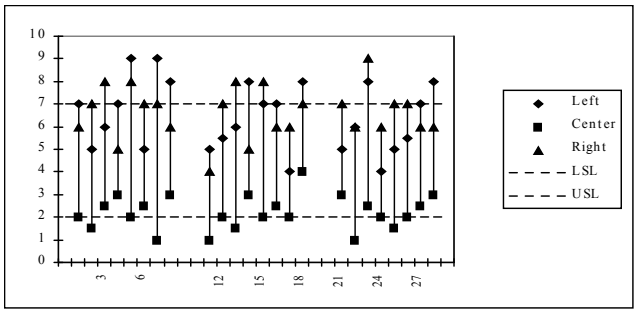
Vendor Batch to Batch

Effect to Cause 2nd level split: temporal & location



Multi-Vari results

Data was taken from 3 sets, 3 readings per part (at each of the 3 clip locations), on all 8 parts off of a single machine. Two separate operators were involved. The results were:

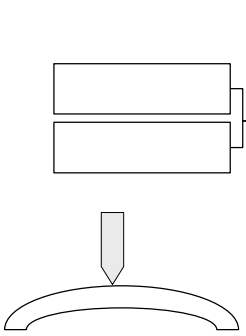


Which category causes the largest change in the Y?

Do you see anything unusual about the data?

With a multi-vari when the majority of the baseline variation in Y is observed, root cause was active in that category and it is not necessary to proceed to test the other categories

Effect to Cause 3rd level split?



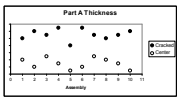
The centers are thin

The ends are thick

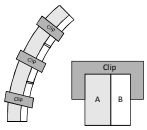
How does this happen?

$D_R = 7.6$

- MSA
- Within Piece
- Piece to Piece
- Lot to Lot
- Time to Time
- Operator to Operator
- Lathe to Lathe



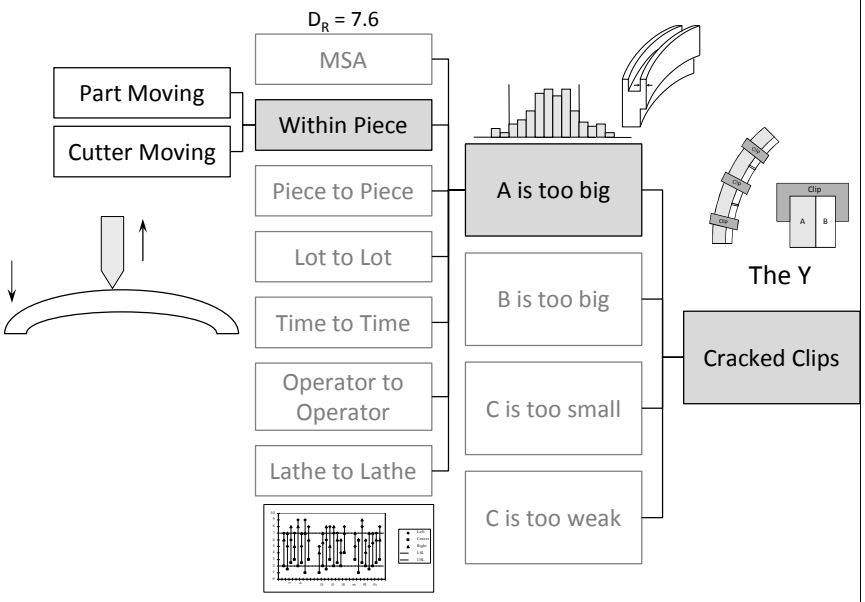
- A is too big
- B is too big
- C is too small
- C is too weak



The Y

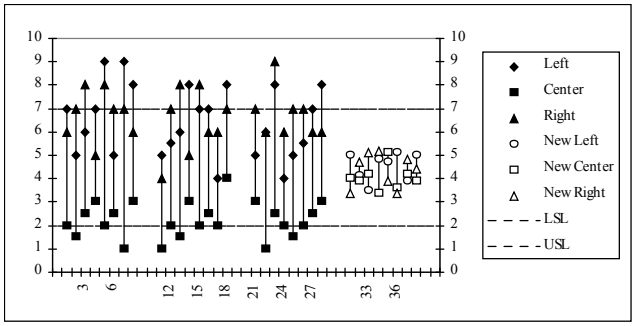
Cracked Clips

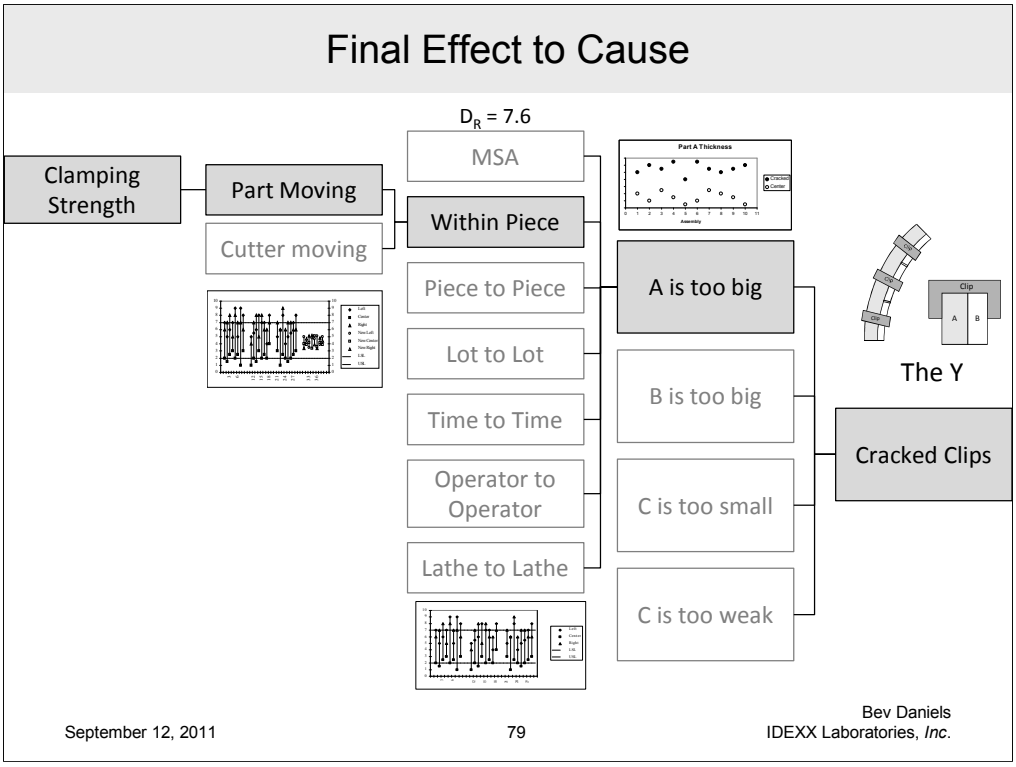
Effect to Cause 3rd level split: process



New process change

A quick experiment on the clamping was tried with the following results:



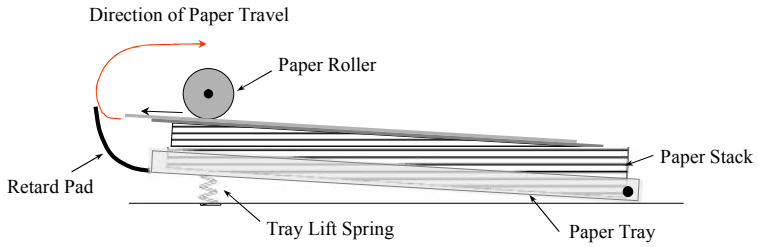


Notice the thumbnails of the critical analyses…although they are not easily read on the diagram, they serve as 'objective evidence' that each level is closed with data, not opinion.

Second Example

A prototype printer

A new low cost printer design. Each of 5 prototypes are exhibiting ~ 5% misfeeds (multiple sheets pulled at a time resulting in a paper jam: What analysis strategy & questions would you use to get to Root Cause?



Engineering's List of Key Factors:

- Downward Force of Paper Roller
- Friction of Paper Roller Pad
- Lift Force of tray Lift Spring
- Friction of Retard Pad

The first question

What is the normal operating condition of the printer?

- This is an inexpensive desktop printer.
- The typical user is not going to be printing a large number of pages
- May have periods where there are several jobs at a single time (prep for the day or a series of meetings)
- May have considerable time period between jobs (as they attend meetings or do other work).
- Mostly cheap copier paper
- May not fill to a full stack each time

The experimental set-up must consider this.

The Y is the presence or absence of a misfeed/jam

The second question

What is the diagnostic pair?

In this case all five prototypes experience the same level of jamming, so the pair cannot be instruments.

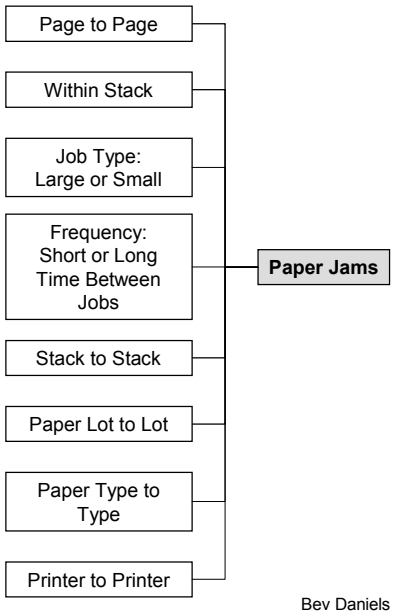
All we are left with is mis-feed events and non mis-feed events.

The first experiment should be to determine what differentiates the mis-feeding events from the non mis-feeding events.

This is typically a time sequence type of investigation or observational study.

This first study can also be used to determine if the jam rate is actually 5%.

Printer Effect to Cause 1st level split: temporal



Time sequence, pattern or categorical correlation?

The Multi-Vari approach would be to analyze the time sequence of mis-feeds: do they happen in any particular pattern?

Under any particular condition such as large print jobs (10+ pages in the job) or small print jobs (1-2 pages)?

Is there a difference between failure rates when running many sequential jobs or when the time between jobs is long?

Is there a difference the location in the stack or are the jams randomly distributed within a stack?

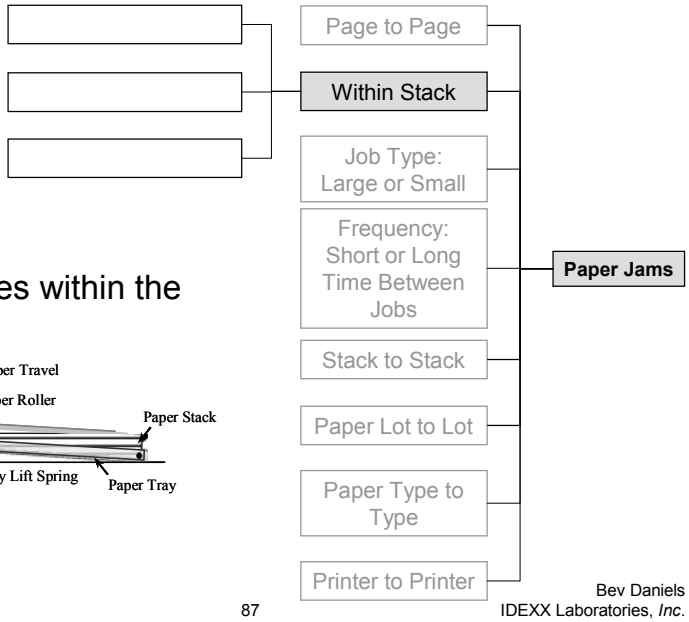
The multi-vari result

In this particular case, all of the mis-feeds occurred early in a ‘full’ stack of 200 sheets.

After the first 50 sheets are fed, there are no more mis-feeds.

It doesn’t matter whether a small job or a large job is run.

Effect to Cause 2nd level split?



What changes within the stack?

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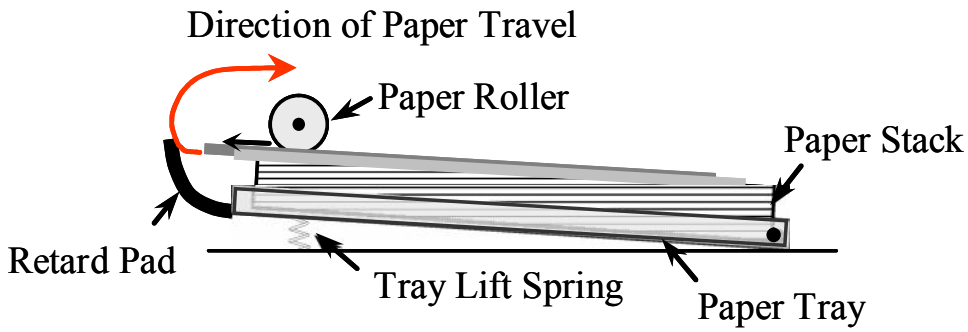
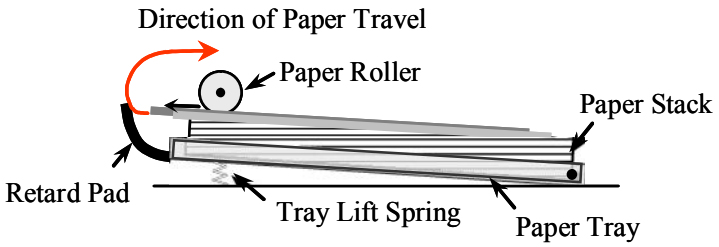
What changes within the stack?



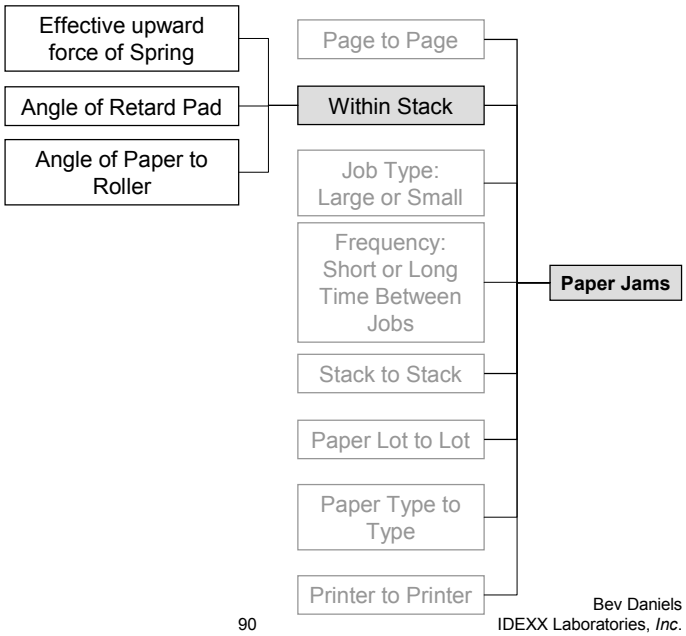
Effect to Cause 2nd level split

There are 3 factors that change *within the stack :*

- The angle at which the paper hits the retard pad
- The force exerted by the tray lift spring thru the stack to the paper roller
- The angle of the top of the stack of paper



Effect to Cause 2nd level split: structural



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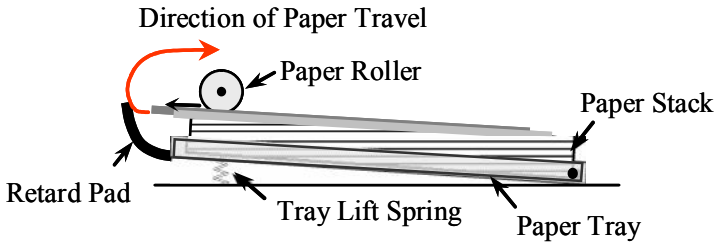
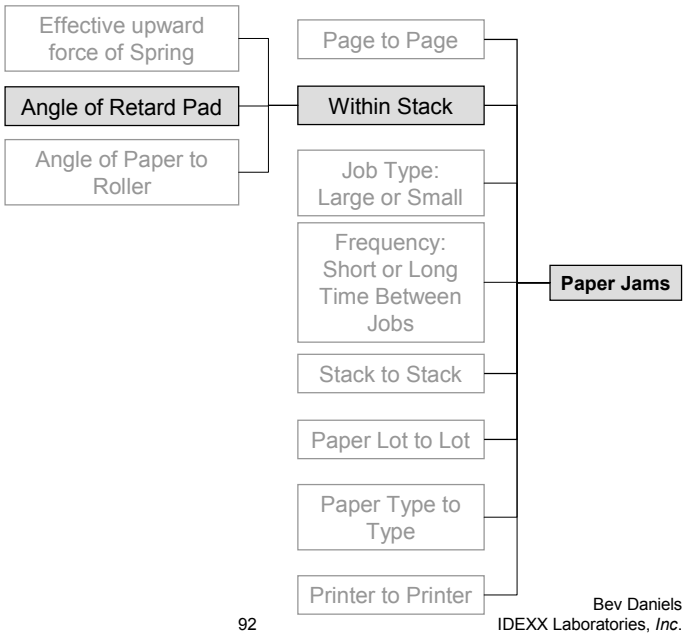
Retard pad

A 2^3 experiment is run on these 3 factors and it is found that the angle of the retard pad is the root cause factor…

The tray lift spring doesn't maintain a single top of the stack height – the thinner the stack, the lower the height. This results in the paper contacting the retard pad at different places.



Final Effect to Cause diagram



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Backup and Supplemental Material

Repeatability and reproducibility[7,8,9]

Effectiveness of the Measurement system of The Y should be confirmed with an appropriate MSA. (NOT a traditional gauge R&R) The MSA should assess repeatability vs actual product variation.

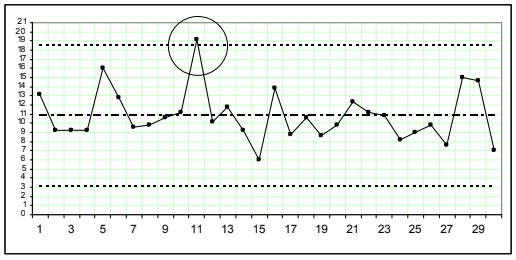
Problems that are intermittent or measurement systems with low discrimination will require an effective increase in sample size

- Multiple runs for intermittent functional failures
- Multiple measurements of the same unit for low discrimination
- Actual increases in sample size if the discrimination is low enough to behave like categorical data.

SPC is not a diagnostic tool

These are **operational definitions** that are of limited applicability for problem solving and are often misunderstood

Assignable Causes are those that create a 'sudden' or 'excursionary' change in a stable process; either in a nonrandom pattern or beyond predictable (historical) limits.



Common Causes are those that create a stable process that behaves randomly within predictable limits.

An Assignable Cause isn't necessarily easy to find and correct

A Common Cause isn't necessarily difficult to find and improve

Draw out the sample space

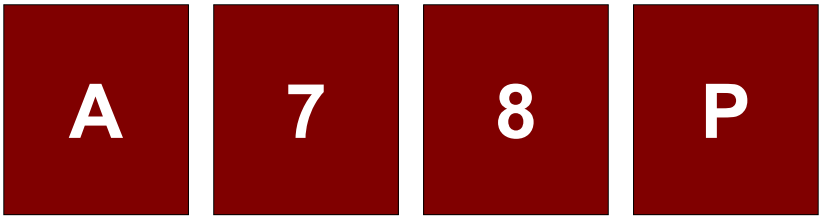
This approach requires us to understand exactly what questions will be answered and what questions will not be answered by any given experimental design.

Exercise: cards[10]

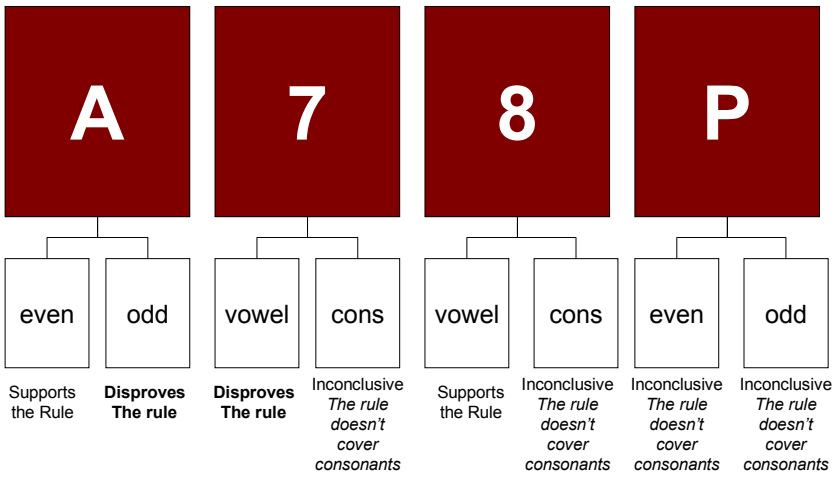
The Rules:

- Each card has a letter on one side and a number on the other
- If the card has a **letter that is a vowel** then the number will be an **even number**

The Game: Given the following 4 cards which cards would you flip to determine if the rule were true or not? You may only flip 1 or 2 cards:



The Answer: A and 7



Anything that disproves a rule is much more informative and therefore powerful

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